Canopy height and plant area index changes in a temperate forest between 2010–2014 using airborne laser scanning

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Canopy height and plant area index changes in a temperate forest between 2010–2014 using airborne laser scanning

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Highlights: Changes in canopy height and plant area index (PAI) in a temperate mixed forest were assessed between 2010 and 2014 using airborne laser scanning. Patterns of canopy height change could be identified and related to forest management and tree growth. PAI changes followed no clear patterns and need further investigation.

Key words: *airborne laser scanning, forest change, canopy height, LAI, PAI, full-waveform.*

Introduction

Airborne laser scanning (ALS) is increasingly being used for forestry applications as well as ecosystem monitoring [1]. Its ability to cover large areas in a spatially continuous way offers unique possibilities to characterize canopy architecture. The fast acquisition and repeatability over time allow for monitoring changes in forested ecosystems, for instance due to forest management, forest degradation, logging, or natural changes like tree growth and tree mortality. Two of the most widely used variables to describe canopy architecture of forests are canopy height and leaf- or plant area index (PAI) [2]. Both are essential variables linked to biomass, ecosystem productivity and biodiversity. In particular, the change in canopy height can be assigned to tree growth, a major ecosystem function and important measure for timber production and increase in biomass. [3]

In this study, we assess changes in canopy height over four years in a temperate mixed forest and compared them to changes in plant area index derived from full-waveform airborne laser scanning data. We expect to detect patterns of forest management (selective logging, clear cutting) and change due to tree growth. However, it was not possible to fully link the canopy height change to PAI change (describing the density of leaves and wood). PAI values might be more heavily affected by varying acquisition geometry and point cloud processing, therefore falsely indicating change patterns due to technology and not ecology. The goal of this paper is to assess the change patterns and to attribute potential change sources: forest management, natural change, data acquisition and quality.

Study area & Data

The study area is a temperate mixed forest at Laegern, Switzerland, covering an area of roughly 2 x 2 km. The site is centered at 8.36° lon, 47.48° lat at an altitude of 680 m a.s.l. Deciduous trees are predominant (mainly *Fagus sylvatica, Fraxinus excelsior, Acer pseudoplatanus*) with patches of needle trees (mainly *Picea abies, Abies alba*). The terrain is characterized by a ridge, spanning from east to west, and a gradient of steep (>45°) to less pronounced (0-10°) slopes north and south of the ridge. The forest is semi-natural, since it is partly managed by selective cutting and natural regeneration [4].

Airborne laser scanning data were acquired on August 1, 2010 using a Riegl LMS-Q680i sensor. Data was recorded at a nominal height of 500 m above ground, resulting in a footprint size of approximately 0.25 m. In 2014, Laegern data was acquired between June 19 and July 25 as part of a larger flight campaign. The same sensor was flown (LMS-Q680i) at a nominal height of 700 m above ground, resulting in a footprint size of approximately 35 cm.

Methods

The processing of the canopy height model (CHM) and PAI values was done for both 2010 and 2014 ALS full-waveform data using the same methodology, described in detail below. Local spatial averaging was applied to reduce the influence of representation errors using a circular averaging filter with a radius of 2 pixels. Differences were subsequently calculated by subtracting the 2010 CHM and PAI values from the 2014 values respectively.

The digital terrain model (DTM) was derived from ALS ground returns, which were extracted using an adaptive multi-scale algorithm, filtered and interpolated to a 1x1 m DTM applying ordinary kriging as described in [5]. For each 1x1 m grid cell, the highest point above DTM was used to calculate the CHM.

The PAI was calculated for 2x2 m grid cells following [5]:

$$PAI = c \cdot ln\left(\frac{1 \cdot t_1 + \frac{1}{2} \cdot t_2 + \ldots + \frac{1}{n} \cdot t_n}{1 \cdot g_1 + \frac{1}{2} \cdot g_2 + \ldots + \frac{1}{n} \cdot g_n}\right)$$

where c is a calibration factor determined from in-situ PAI measurements, $t_1, t_2, \ldots, t_n$ are the total number of echoes for each echo type weighted by the total number of returns (*1, 2, ..., n* returns) and $g_1, g_2, \ldots, g_n$ are the corresponding number of ground echoes respectively. The echoes for each grid cell were determined by selecting the canopy echoes first, which lie within the 2x2 m grid and more than 4 m above ground. The pulses of the canopy echoes were then tracked to the ground to find the corresponding ground echoes below 4 m above ground, no matter if they lie inside or outside the current grid cell. This leads to a reduced impact of scan angle and scan geometry compared to [5], where total number of echoes and ground echoes were selected strictly within the vertical column of each 2x2 m grid cell. Moreover, the point cloud was restricted to a maximum of 100 pulses per 2x2 m grid cell to reduce bias from extremely high pulse densities in densely vegetated areas.

Results & Discussion

Figure 1 shows the difference images of 2014 CHM and PAI minus 2010 CHM and PAI respectively. The CHM difference map shows clear patterns. The larger dark blue patches show areas of clear cutting, often connected to forest roads. There are also many areas of selective cutting, where single trees were taken out. In total, roughly 48'000 m^2 of forested area was clear-cut in the time between 2010 and 2014. Besides these clear negative change values, there are many patches showing strong increase in canopy height. Especially in the center region, many areas with more than 2 m increase in canopy height due to tree growth were identified. These areas can be assigned to fast growing rejuvenating forest. In 2010, the mean canopy height of these patches was 10.6 m ± 5.8 m.

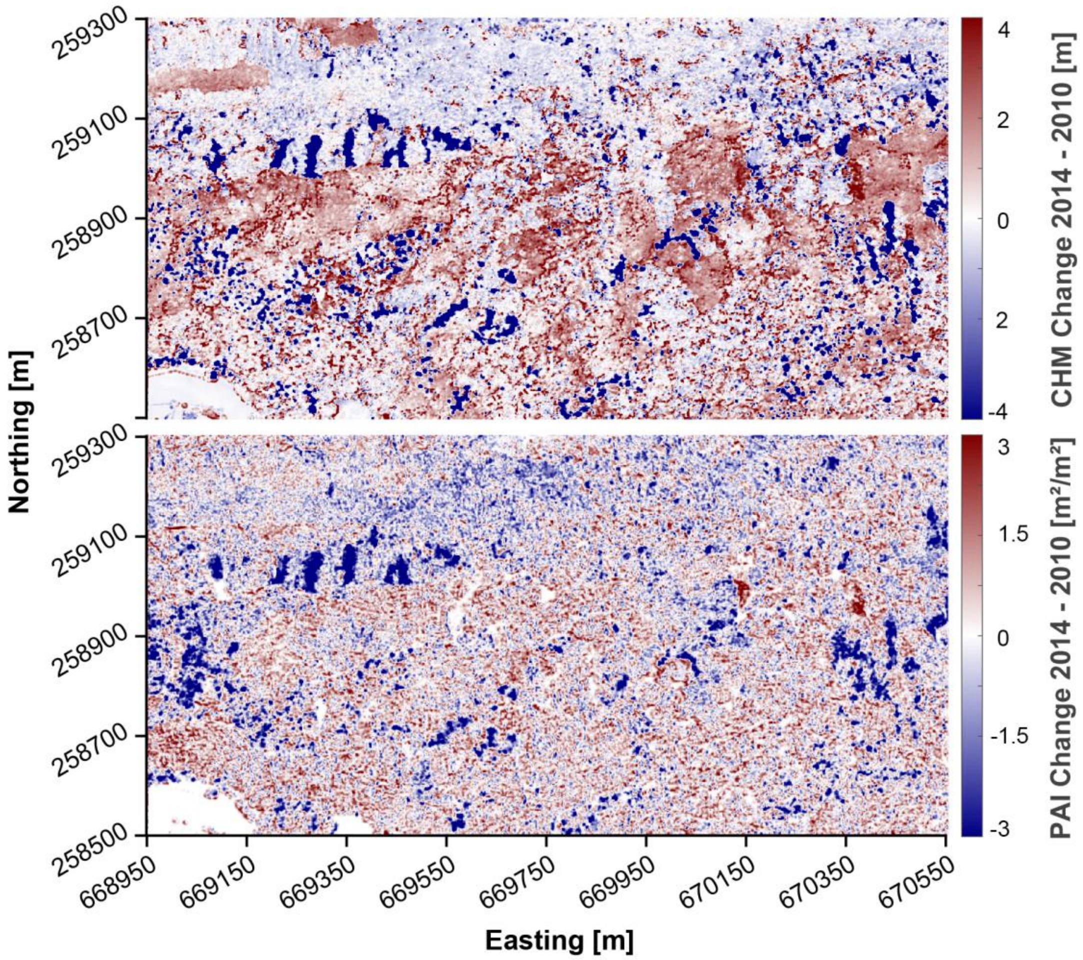

Figure 1: Changes in CHM and PAI between 2010 and 2014 of a 1600 x 800 m subset of the study area (Swiss coordinates CH1903 LV95).

There might be minor local CHM change due to small differences in geo-location of the ALS data. Both datasets have a positional accuracy of < 0.15 m in vertical and < 0.5 m in horizontal direction, as estimated from terrestrially surveyed rooftops. There was no additional co-registration performed between the two datasets. Another reason for the local CHM differences might be representation errors, where the same 3D objects are scanned from two different angles. This can cause CHM differences, which are not linked with the positional accuracy of the datasets. Local spatial averaging helped to reduce these effects, which resulted in a clearer change pattern (Figure 1).

There is a slight underestimation of canopy height in the 2014 dataset compared to 2010. In 2014, the canopy top was probably not captured as reliably as in 2010 due to lower pulse density and higher flight altitude. As reported in [6], an increase in tree height underestimation with increasing flight altitude can be caused by missing the tree tops due to lower pulse density or lower energy being reflected from the canopy surface. Differences in the DTM can represent another source of error, especially in areas of dense understory vegetation. Within the Laegern study area, the mean difference between the DTM of 2010 and 2014 is 0.3 m ± 0.2 m.

The PAI difference map in Figure 1 is more difficult to interpret. The areas of clear cutting and selective cutting can be seen as well. However, all other parts are rather noisy. Some patches with an increase in canopy height also show an increase in PAI, but not all patterns of CHM and PAI change are consistent. In some parts, PAI might already be saturated and not showing an increase in PAI where there is still an increase in CHM observed. When comparing PAI values derived from different acquisitions, representation errors might have a stronger influence than for CHM comparisons. The two datasets were acquired with a different scan geometry: One was flown in east-west direction, whereas the other was flown in north-south direction. So depending on the local observation angle, different parts of the crowns and the ground were observed.

There is no obvious pattern related to pulse density variation, but the pulse density can influence the PAI retrieval in very densely forested areas with few or no ground returns.

Conclusion

We applied CHM and PAI retrieval algorithms on ALS full-waveform data of 2010 and 2014 to compare changes in canopy height and density. Possible sources of the main canopy height changes are forest management (clear cutting, selective cutting) and tree growth (young fast growing trees). Representation errors, differences in data acquisition and geo-correction may lead to a slightly noisy pattern and potential underestimation of canopy height in 2014 compared to 2010. Except for the selective cutting, there are no clear trends in plant area index change. The PAI change patterns are noisier and partly inconsistent with CHM change. Further studies are needed to investigate the influence of pulse density and flight geometry on the PAI retrieval.

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